

X-ray detector on 2U Cubesat BeEagleSAT of QB50

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Abstract—BeEagleSAT is a 2 Unit cubesat to be launched within the EU FP7 project QB 50. It is been produced by Istanbul Technical University and Turkish Air Force Academy. Sabanci University will provide a CdZnTe based semiconductor X-ray detector and associated readout electronics. The detector will utilize cross strip geometry to test the detection system in space, but it will not carry a mask for imaging. The readout will be established by an application specific integrated circuit controlled by a microcontroller. The system will have its own battery and will be turned on intermittently due to power and telemetry constraints. It will characterize the hard X-ray background in 20-150 keV at low Earth orbit conditions as a function of altitude.

Keywords—X-rays; cubesats; semiconductor detectors; CdZnTe detectors

I. INTRODUCTION

Many interesting astrophysical objects such as black holes, neutron stars, clusters of galaxies, gamma-ray bursts are intense X-ray emitters. The high energy emission from such exotic objects are often transient that may last from a few seconds to months depending on the nature of the object. Since the atmosphere absorbs X-rays, observations of these interesting objects must be made in space. There are various large X-ray observatories orbiting the Earth (*Chandra*, *XMM-Newton*, *INTEGRAL*, *Suzaku* to name a few) as well as smaller explorer type missions (*Swift*, *NuSTAR* are two examples). These satellites employ different techniques to observe the X-ray sky. For example *Chandra*, *Suzaku* and *XMM-Newton* employ X-ray telescopes and operate up to 10 keV with good energy and spatial resolution, *NuSTAR* has a specially coated X-ray telescope that can go up to 70 keV, and *INTEGRAL* and *Swift* have coded mask imaging systems[1] that can observe large areas of the sky up to a few hundred keVs.

These satellites orbit at a wide range of altitudes, some are at highly elliptical orbits (*Chandra*, *XMM-Newton*, *INTEGRAL*), and some are at low-Earth orbit (*Swift*, *NuSTAR*). *MAXI*, a Japanese X-ray all sky monitor[2] is on the International Space Station (ISS), and there are plans to have more X-ray detector systems on the ISS. One of the most critical issues of X-ray instrumentation in space is determining the background. There are contributions from instrumental background, interaction of charged particles with the detector material, secondary emission from interactions of charged particles with the surroundings of the detector and also the cosmic background mostly due to diffuse emission from the

galactic and extragalactic X-ray sources. It is extremely important to characterize the properties of X-ray background for all altitudes and external environments.

Sabanci University High Energy Astrophysics Detector Laboratory has been established to characterize room temperature semiconductor detectors, and to design and produce X-ray detector systems utilizing CdZnTe material. To qualify detector systems for space, a collaboration has been set up between Sabanci University, Istanbul Technical University and the Turkish Air Force Academy to place a CdZnTe based semiconductor X-ray detector system on board a 2U Cubesat named BeEagleSAT. BeEagleSAT (see Fig. 1. for a solidwork model of the satellite) is part of the QB50[3] network which utilizes about 40 double cubesats, separated by a few hundred kilometers and carrying identical sensors to study the temporal and spatial variations of a number of key constituents and parameters in the lower thermosphere (90-320 km). The QB50 project is supported by the EU 7th Framework Program.

CdZnTe and similar semiconductor detector systems are commonly used in astrophysical observing satellites. *INTEGRAL*-ISGRI[4] detector, and *Swift*-BAT[5] detector utilize CdTe and CdZnTe semiconductor detectors with coded mask imaging systems. For these systems, the detector plane consists of many individual crystal pieces with an energy range of 20-200 keV. On the other hand, the system on *NuSTAR* utilizes pixellated CdZnTe detectors. The pixellated design and its low-noise readout chip allow a minimum detectable X-ray energy as low as 3 keV with an energy resolution of less than 1 keV[6].

The detector system we will place on the BeEagleSAT has orthogonal strips for position resolution. Such orthogonal strip detectors have been proposed as detector material for X-ray

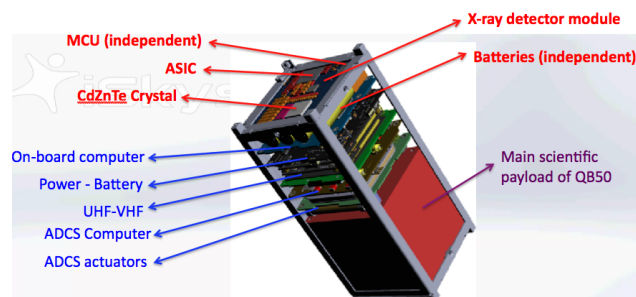


Fig. 1. BeEagleSat Solidworks model that shows the main components. The X-ray detector is on top, and its parts are written in red.

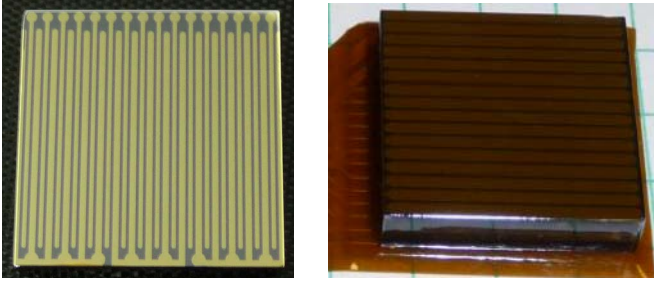


Fig. 2. Left: anode and steering electrode strips laid on CdZnTe crystal. Right: cathode strips laid on CdZnTe crystal. The crystal shown in the picture is 20x20x5 mm³.

observatories before[7], but they have never been realized in space. The main advantage of orthogonal strip detectors is the low number of electrical readout channels compared to pixellated detectors, however they suffer from higher noise and higher minimum detectable energies. For small satellite systems, having low number of readout channels have advantages in terms of power and space outweighing the problems with the minimum energy and energy resolution.

II. CDZnTE DETECTOR SYSTEM

The CdZnTe detector system we design consists of an orthogonal strip CdZnTe crystal, readout application specific integrated circuit (RENA-3b ASIC)[8], its own microprocessor, analog-to-digital converter, power and associated coupling circuits and its own batteries (see Fig. 1).

A. CdZnTe crystal

The system will utilize imaging grade Redlen CdZnTe crystal that has dimensions of 20 x 20 x 3 mm. Gold strips are deposited on both sides of the detector orthogonally to have position determination capability (see Fig. 2). The side that faces the board has 16 anode strips that are 0.3 mm wide and kept at ground potential. In between the anodes, there are 3 sets of steering electrodes that are 0.45 mm wide and kept at a lower potential compared to anodes (left, Fig. 2). Such configurations are used for two purposes, to steer electrons towards the anodes, and also to enhance energy resolution of anodes by the small pixel effect[9]. On the opposite faces, there are 16 orthogonal cathode strips that are 1 mm wide and kept at -300V. The pitch for both the anodes and the cathodes is 1.2 mm (right, Fig. 2). The cathode, anode and the steering electrode widths are determined through extensive simulations and measurements. The widths we use provide the optimal performance in terms of charge collection and sharing, energy resolution and noise due to leakage currents. The signal and voltage are carried to cathodes by flex strips. Even though the crystal has position sensitivity, it does not include a coded mask, so it will not have imaging capabilities.

B. Readout Chip

The readout of the 35 channels will be done by RENA-3b readout chip, which is a low-noise, 36-channel, self-trigger, self-resetting charge sensitive amplifier/shaper integrated circuit[8]. The chip is especially designed for use with position-sensitive, spectroscopy-grade radiation detectors for

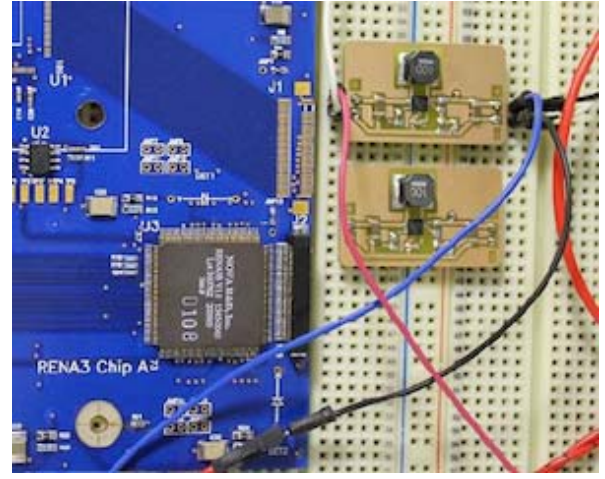


Fig. 3. Picture of RENA-3 readout chip along with some of the prototype voltage converters we try.

various applications. One major advantage of the chip for space applications is its low power consumption of <6 mW per channel.

The digital part of the chip and the analog-to-digital converter (ADC) is controlled by MSP 430 microcontroller. The channels that trigger are registered by the microcontroller, and then the peak detector analog outputs are read sequentially through the ADC. The peak values for each channel (as a single event normally induces signals at multiple cathodes, one or more anodes, and the steering electrode), and the timestamps are then saved in 256 K flash memory.

C. Power

The X-ray detector module requires several voltage inputs for operation. On the other hand the battery provides a single potential, which will change in time. The power will be supplied by 7 SOCl₂ batteries[10]. These batteries are not rechargeable, and the system will be turned on intermittently at different altitudes for maximum scientific gain. The details of the power management of the module are shown in Fig. 4, and the total power requirement and lifetime calculation is provided in Table 1. According to this calculation, the batteries will last for a total of 143 hours of operation. Below we provide some details of the methods of conversion for different voltages.

3 mm thick CdZnTe crystal requires 300 V to operate. Currently we are working on four alternative methods to obtain this voltage: push-pull, flyback, forward DC-DC converters (see schematics for these alternatives in Fig. 5) and AC-DC converters. All designs require a transformer, and electromagnetic isolation is essential to reduce noise in the readout system.

RENA 3 requires 5V for digital operation, 1.5V and 3.5V for setting reference voltages for the peak detector, and 2V very low noise reference voltage. These potentials will be produced by low-dropout (LDO) regulators, and buck-boost converters. The efficiency of the circuits is greater than 90%. The simulations and noise analysis with prototype circuits

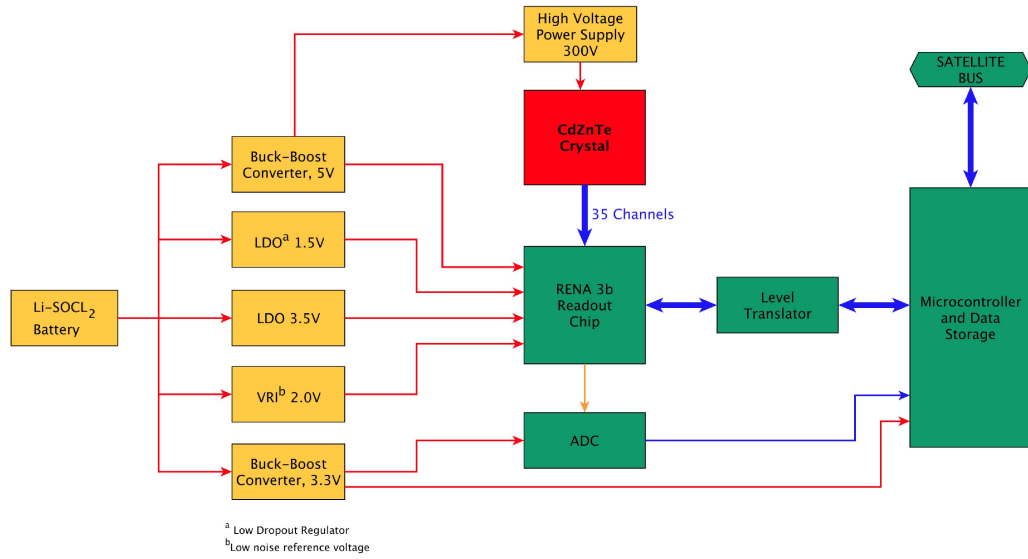


Fig. 4. Electrical block diagram of the CdZnTe detector system.

for all power modules (Fig. 3 for example of prototypes) are underway at the time of submission of this work. After investigating the simulation results and prototype measurements we will finalize the type of voltage converters.

III. SPACECRAFT INTEGRATION AND THE SOFTWARE FUNCTIONAL BLOCK DIAGRAM

Given the demanding requirements[11] of the QB50 primary payload in terms of power, telemetry, and computing power we have decided to design the CdZnTe detector module as independent from the QB50 systems as possible.

TABLE I. POWER BUDGET

Battery	
Capacity (each)	12,96 Whr
Number of batteries	7
Total available energy	90,72 Whr
Efficiency	
For 3,3V conversion	%90
For 5V conversion	%93
5 V Component currents	
Level translator	8 mA
ADC	22 mA
RENA	54,6 mA
HV generator	30 mA
3.3 V Component currents	
Microcontroller	3 mA
Total power required	633 mW
Available operation time	143 hours

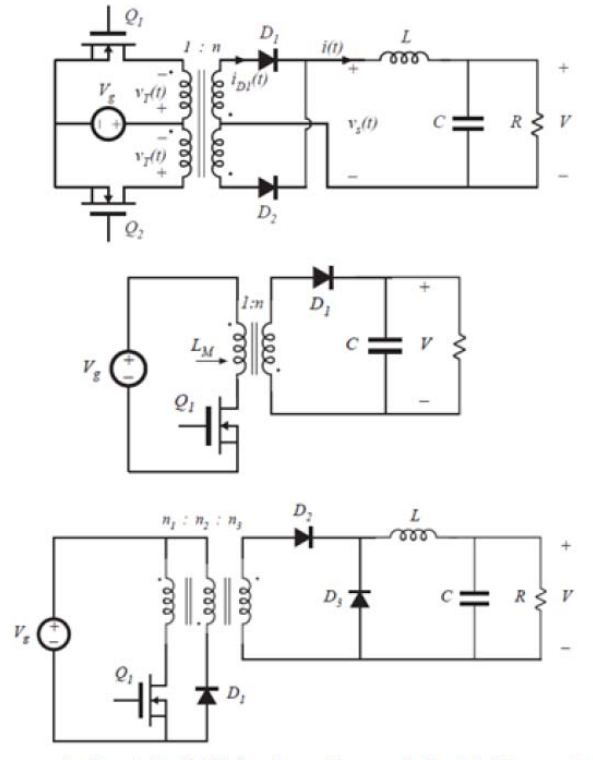


Fig. 5. Circuit diagrams for the 5V – 300 V conversion. Top: push-pull Middle: flyback Bottom: forward DC-DC

For this reason we have used our own batteries for power, and we will not tap power from the solar cells. We also employed our own microprocessor

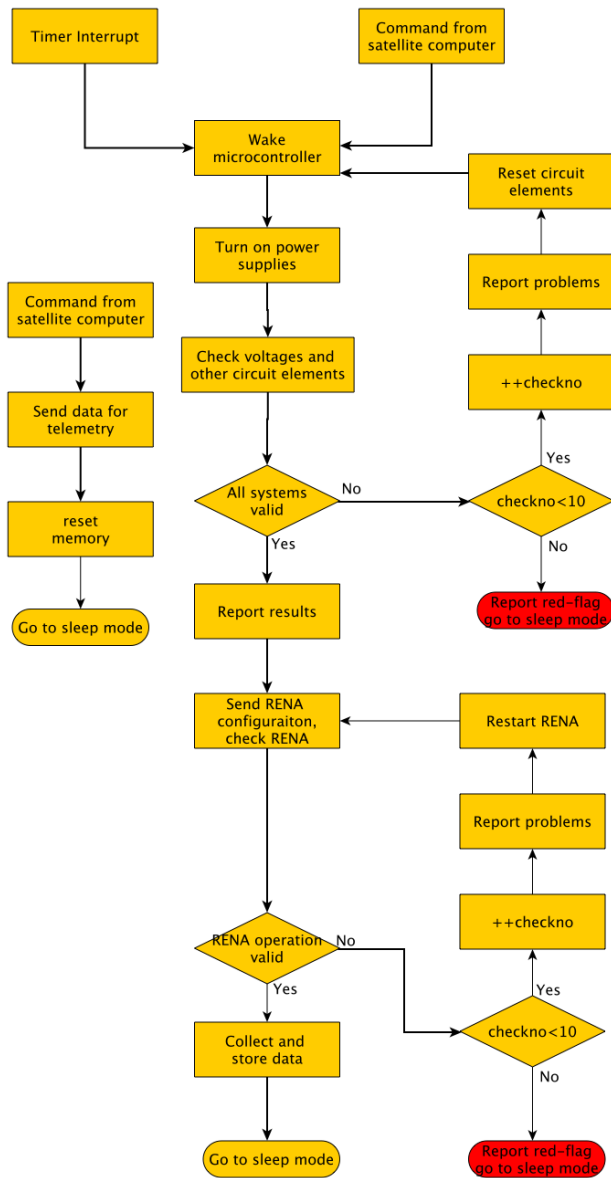


Fig. 6. Functional block diagram of the detector operation.

The block diagram that describes the operation of the detector is shown in Fig. 6. Once the initial altitude of the spacecraft is finalized, we will be able to find out the altitude as a function of time. We will turn on the system intermittently to cover as large altitude range as possible. Once the interrupt is sent from the satellite computer to start operation, our microprocessor will wake up. It will then turn on power-converters and measure voltages. If one or more converters do not work properly, it will prepare a report log, reset all circuits, and turn them on again. This check will be done at most 10 times, and if the resets do not work it will prepare a red-flag report and go back to sleep mode and will wait for the next interrupt or reprogramming. If all converters work properly, then RENA will be turned on. RENA operation will also be checked, and RENA will be reset up to 10 times if necessary. If RENA works fine, then the data will be taken for a

predetermined time (or total number of counts). This data and the associated timestamps will be saved in flash memory card.

When the spacecraft is ready for telemetry another interrupt will be sent from the main computer which will receive the data and downlink to the ground station.

IV. CONCLUSIONS

CdZnTe X-ray detector systems have been utilized in large satellite observatories, mid-size satellite observatories, even in cubesats (AAUSat-2, launched[12], The Cosmic X-Ray Background Nanosat, CXBN, in preparation[13]). The successful operation of the payload will result in technology demonstration for CdZnTe strip detectors in space and test space readiness of the RENA-3b chip. It will also determine the X-ray background at low altitudes.

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